



Drivers promoting renewable energy: A dynamic panel approach[☆]

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ABSTRACT

We study the commitment to renewable energy sources, focusing on a set of 24 European countries, and applying panel dynamic estimators. Europe is a leading player in the fight against climate change, and the estimators we use reveal themselves to be appropriate in handling the persistency effect on renewables. The level of renewable energy use in the previous period has a positive and highly significant effect on the current level of use. Traditional energy sources restrain the impetus towards renewables. Social awareness of sustainability, climate change mitigation and CO₂ reduction targets are not enough to motivate the switch from traditional to renewables energy sources. Income and prices of fossil-based fuels were not significant for the development of renewables in the period from 1990 to 2006, suggesting that it was not the market that encouraged renewables.

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1. Introduction

The choice of energy sources is essential for maintaining and even improving present-day living standards, within a context of a trade-off between the planet's survival and the economy's sustainability. Even in the absence of a consensus about causes, there is, in fact, no longer any doubt that climate change is happening, and is particularly visible in the melting of enormous glaciers. It may be a consequence of a cyclical phenomenon, a consequence of greenhouse gas (GHG) emissions resulting from combustion of fossil-based fuels, or a mix of both. This has been a continuous

and dynamic process. Through dynamic panel data estimators, in this paper, we analyze the commitment to produce energy from renewable sources, which should be a continuous commitment. We intend to understand the determinants that have both encouraged and hampered that commitment.

The characteristic of not depleting over time, resulting from being regenerative resources, gives renewables the potential to provide two roles in sustainability: (i) on the one hand, they can help to solve the problem of depleting fossil-based sources, namely oil, coal and natural gas reserves; and (ii) on the other hand, renewable energy (hereafter RE) sources are cleaner sources that could help fight climate change since they come from indigenous or local resources with negligible emissions of GHG.

Policy decisions are faced with the trade-off between choosing global warming and cooling the economy. This is a breeding ground for free-riding phenomena to emerge. Countries publicize that they understand the benefit of investing in renewable energy.

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Table 1
Joint significance and linear restriction tests of prices.

	(I) Fixed effects (AR1)	(II) GMM-dif	(III) GMM-sys	LSDVC	(IV) Initial (AB)	(V) Initial (AH)	(VI) Initial (BB)
Joint significance test	3.31**	15.04***	0.11	5.81	4.01	2.59	
Linear restriction test	0.0963 (0.0576)	−0.0578 (0.1066)	−0.0294 (0.1040)	−0.0216(0.0920)	−0.0224 (0.1008)	−0.0315 (0.1007)	

Notes: GMM-dif [31]; GMM-sys [32]; LSDVC [33]. The joint significance test is a test $F(N(0,1))$ for model (I) and a test $Wald(\chi^2)$ for all others. The joint significance test has the null hypothesis of $H_0: \beta_1 = \beta_2 = \beta_3 = 0$, with β_i meaning the coefficient of i prices, and i = oil, natural gas and coal. The linear restriction test has the null hypothesis of $H_0: \beta_1 + \beta_2 + \beta_3 = 0$. Standard deviations are reported in brackets; ***, **, denote significance at 1, and 5% significance level, respectively.

However, everyone wants transfer to their peers, the large costs of making investments in renewables. Besides, politicians, who are the policymakers, tend to reveal a strong preference for the short run. Indeed, in the long run, they will no longer be in the race for re-election. The oil industry could be at risk if the connection between global warming and fossil fuels is firmly established. At the same time, this industry constitutes a powerful economic and geopolitical lobby since, as is widely known, it is a large funder of political campaigns around the world.

To better understand the drivers towards RE use, it is worth considering the early steps taken towards raising awareness about global warming and climate change. One of the first steps was in 1990, with Resolution 45/212 of 21 December 1990 of the United Nations General Assembly, establishing the International Negotiating Committee for a Framework Convention on Climate Change. Europe has been one of the political blocs that has most prominently fought climate changes. We study the factors explaining the use of RE, from the year 1990 until 2006, in a set of twenty-four European countries. The commitment to renewable energy is a continuous path. Unlike the sparse empirical literature, for example [1], we use panel dynamic estimators to enable the analysis of RE use as a persistent process.

Our contribution to the literature is threefold: (i) we add empirical knowledge about drivers towards renewable energy use, for a large span of time in a set of European countries; (ii) we show that prices of fossil-based fuels may not be significant in explaining the choice of renewables; and (iii) we apply a dynamic panel approach which is new in literature.

The remainder of this paper is structured as follows. Section 2 presents the literature and contextualizes the debate about RE. Section 3 discusses the explanatory variables, defines the hypotheses,

reveals data and presents methodology. Section 4 shows the main results. Section 5 provides a discussion of the results. Finally, Section 6 presents major contributions and concludes.

2. Commitment to renewables

There is a vast recent literature on factors promoting the use of RE sources. This literature is predominantly normative, either pointing out factors that should influence RE commitment [2], or listing the potential benefits and costs that may result from its use [3]. Much of this literature consists of descriptive analysis and surveys, which present a review of the current situation concerning RE within several countries, such as the Netherlands [4], Sweden [2], Germany [5], the Baltic States [6], Europe [7], Turkey [8], Crete [9], the USA [10], Abu Dhabi [11], and India [12]. However, there is a lack of empirical evidence about determinants influencing the option for renewables. The scarce empirical literature is focused mainly on the USA scenario [1,13], and over a short span of time. Menz and Vachon [13] studied wind power development for one year-data of 30 States in the USA, by applying the Ordinary Least Squares approach. For a span of time, from 1998 to 2006, Carley [1] estimated a model of fixed effects, and a model of fixed effects with vector decomposition, for 48 States in the USA.

Energy is an economically strategic sector that ought to require political and policy guidance. The established socio-economic system is based on the conventional sources of energy, mainly fossil-based [7], but energy policies cannot ignore the potential of RE [14], though they are faced with barriers for implementing them. Public intervention ought to correct market failure. In recent years, governments have chosen to intervene by granting incentives and

Table 2
Results of parsimonious models.

Independent variable	Dependent variable $CRES_{i,t}$					
	(I) Fixed effects (AR1)	(II) GMM- <i>dif</i>	(III) GMM-sys	LSDVC		
				(IV) Initial (AB)	(V) Initial (AH)	(VI) Initial (BB)
$CRES_{i,t-1}$		0.3115*** (0.0986)	0.6943*** (0.0837)	0.6354*** (0.0409)	0.6359*** (0.0471)	0.7180*** (0.0347)
$CO2PC_{i,t}$	−0.0002** (0.0001)	−0.0003** (0.0001)	−0.0003* (0.0002)	−0.0002*** (0.0001)	−0.0002** (0.0001)	−0.0002** (0.0001)
$ENERGPC_{i,t}$	0.0010** (0.0002)	0.0010** (0.0004)	0.0008* (0.0005)	0.0008*** (0.0002)	0.0008*** (0.0002)	0.0006*** (0.0002)
$SOILEG_{i,t}$	−0.1692*** (0.0174)	−0.1765*** (0.0390)	−0.1664*** (0.0326)	−0.0836*** (0.0175)	−0.0814*** (0.0206)	−0.0868*** (0.0182)
$SGASEG_{i,t}$	−0.0705*** (0.0117)	−0.0918** (0.0463)	−0.1225** (0.0488)	−0.0502*** (0.0113)	−0.0506*** (0.0133)	−0.0521*** (0.0117)
$SCOALEG_{i,t}$	−0.1340*** (0.0163)	−0.1215*** (0.0335)	−0.1250*** (0.0243)	−0.0589*** (0.0131)	−0.0566*** (0.0159)	−0.0583*** (0.0139)
$SNUCLEG_{i,t}$	−0.2641*** (0.0229)	−0.2726** (0.1063)	−0.2077*** (0.0495)	−0.1231*** (0.0229)	−0.1182*** (0.0267)	−0.1297*** (0.0231)
$IMPTDP_{i,t}$	−0.0431*** (0.0109)	−0.0168 (0.0130)	−0.0195 (0.0173)	−0.0225*** (0.0068)	−0.0237*** (0.0088)	−0.0223*** (0.0068)
CONS	23.849*** (0.2085)	18.649*** (4.6836)	15.618*** (3.2918)			
Instruments		GMM- <i>dif</i>	GMM-sys			
Observations	384	360	384	384	384	384
$Wald(\chi^2)$		97.64***	2131.64***			
$F(N(0,1))$	40.03***					
Sargan(χ^2)		13.563	12.0506			
$m1(N(0,1))$		−2.189**	−2.3488**			
$m2(N(0,1))$		0.998	1.0483			

Notes: The Sargan test of over-identifying restrictions tests H_0 of instrument validity; the $m1$ test is a test for first-order autocorrelation of residuals, testing H_0 of no first-order autocorrelation; the $m2$ test is a test for second-order autocorrelation of residuals, under H_0 of no second-order autocorrelation. ***, **, *, denote significance at 1, 5 and 10% significance level, respectively. Standard errors are reported in brackets: robust in models (II) and (III); and bootstrapped in models (IV), (V) and (VI), with 100 replications. All estimates were controlled to include the time effects, although not reported for simplicity. For models (I) to (III) we provide two-step estimations to obtain efficiency gains by reducing bias [34].

subsidies for RE. Authors such as, Johnstone et al. [15] and Frondel et al. [16] studied the impact of public policies on RE, without consensus as to the effects. Johnstone et al. [15] concluded that the effect of public policies largely depends on the kind of RE source. In Germany, Frondel et al. [16] present a very critical perspective on the effects that public support has had on RE. They pointed out that such systems impose high costs to society and they contribute to making the country more dependent on imported gas. These incentives do not encourage competition among producers, lead to dependency on existing technologies, and do not promote innovation. The authors advance that the first step should be to improve technological efficiency through R&D. It is worth emphasizing that, for other sources of energy, such as coal, oil and nuclear, significant initial investment was also required [7]. Furthermore, the takeoff phase was stimulated, either by public credit guarantees or public companies with enormous market power.

Investment in RE allows the paradigm to be changed from a carbon-based economy to a sustainable one. In addition to being exhaustible, fossil-based fuels are pollutants, which could lead to global warming and, as a consequence, the degradation of the environment and quality of life on the planet, namely for future generations. This outcome necessarily requires the use of new sources of energy, diminishing standards of living and stagnating economic growth as little as possible, in order to ensure a sustainable future. Under the guidelines of diversification and preparation for the future, even oil-producing states are placing strong bets on developing cleantech solutions, such as Saudi Arabia or Abu Dhabi [11].

To enhance RE use, the commitment of all economic agents is required. Citizens need to be able to bear initial direct economic costs, namely by carrying regulatory costs, paying higher costs and taxes. Furthermore, social pressure and social acceptance are relevant factors to the challenges of RE [17]. On the government side, energy policies may guarantee a stable path for the investments. For the Netherlands, van Rooijen and van Wees [4], and for Sweden, Wang [2], conclude that both the uncertainty and discontinuity of energy policies are the main causes of small development of RE in these countries. Europe is following a path of continuity and definition of objectives for the medium and long run. A good example is the targets set in its directives [18,19] for RE use in the European Union (EU).

As far as we know, the literature has not made an empirical assessment of the drivers towards RE, either over a long span of time, or by applying panel dynamic estimators. This approach would seem to be appropriate since it enables renewable energy use to be analyzed as a dynamic process. The following section presents, in detail, the sources of data, the variables, the model, and the estimation procedures.

3. Data and methods

Data from the year 1990 to 2006 for twenty-four European countries was used. We focus on EU Members on the 1st of January 2007 (with the exceptions of Cyprus, Bulgaria, Latvia, Lithuania, Malta and Romania, countries for which data are available only after the 1990s) and Iceland, Switzerland and Turkey. The latter are usually referred to in the EU technical reports because they were candidates applying for EU membership (see, for instance, [20]). Table A1, in Appendix A, shows the definition of variables, source and descriptive statistics.

3.1. Variables and hypotheses

Rather than explain the total amount of renewable energy, we work upon explaining the relative weight of RE in the total primary energy supply. We use as a dependent variable the Contribution of Renewables to total Energy Supply (*CRES*), measured as the per-

centage of total primary energy supply. The explanatory variables are those common in the literature. The research evolves with the specification of hypotheses, linked with the explanatory variables, as follows: *Continuous commitment to renewables* (*CRES*_{*t-1*}). The decision to make use of renewable sources of energy cannot be a decision for months or even for a year. It implies large investments and it makes sense to persist in developing that technology. We pursue by testing the hypothesis: *H1 – There is a persistence effect in the commitment to RE*. We expect to verify a continuous commitment to RE, or rather, a positive relationship between *CRES* in the previous and current periods. *Carbon dioxide emissions per capita* (*CO2PC*). The climate change phenomenon and global warming are closely linked to carbon dioxide, chlorofluorocarbons, methane, nitric acid and ozone greenhouse gases. The most common gas is carbon dioxide (hereafter *CO*₂) and it is both a benchmark and a target in international treaties. Efforts to fight global warming and move towards sustainability of the planet lead to the creation of the carbon market. Known as the European Union Emissions Trading Scheme, the EU has the largest multi-national experiment in emissions trading system for carbon dioxide. The variable *CO*₂ is commonly used in literature [21–23]. We control for *CO2PC* and we test the hypothesis: *H2 – Carbon dioxide emissions impacts on renewables deployment*. The sign of the effect will be positive if higher levels of *CO2PC* create awareness in society about environmental issues and sustainability. This will result in political pressure to encourage the use of energy generated from renewable sources. The sign of the effect will be negative if there is society alienation of environmental issues and sustainability. This will enable the use of fossil sources of energy, to the detriment of renewables. For a social acceptance analysis of renewable energy innovation, see [17]. *Energy consumption per capita* (*ENERGPC*). The additional consumption of energy can be accomplished in three ways: (i) from traditional sources, namely fossil-based fuels, (ii) from alternative renewable sources; and (iii) from both, or rather, a mix between additional use of fossil fuels and renewables. In this way, the additional energy consumption may be an incentive to develop renewables. We test the hypothesis: *H3 – Larger energy consumption per capita motivates renewable energy deployment*. This variable could be seen as a development indicator. It is expected that larger consumption will create pressure on the production of energy generated from local renewable sources. *Contribution of fossil sources of coal, oil and natural gas for electricity generation* (*SCOLEG*, *SOILEG* and *SGASEG*). Power exercised by interest groups associated with fossil energy sources, particularly the oil industry, is often cited as one of the major drivers that influence the definition of public policies. The impact these industries have on the economy in general and in politics in particular, may affect the strategic orientations of governments for the energy sector, namely influencing energy policies. It would therefore seem to be a factor that should be taken into account in explaining the representativeness of the renewable energy supply. The lobbying effect is reported in the literature [24]. Following [25], we control for the contribution of the traditional energy sources on electricity generation. We test the following hypothesis: *H4 – There is a negative relationship between the weight of the fossil sources for electricity generation and the use of renewables*. We expect to corroborate the lobby effect, which holds back the efforts to improve the use of renewables. *Contribution of nuclear energy for electricity generation* (*SNUCLEG*). Nuclear energy source is economically viable when scale economies can be exploited. Like the effect of lobbying carried out by supporters of fossil-based fuels, we also expect the use of nuclear energy source to impede the development of RE. The hypothesis to test is: *H5 – The use of nuclear power demotivates the use of RE*. *Energy security* (*IMPTDP*). Looking for energy self-sufficiency is suggested by the literature [26] as an enticement to explore local sources of energy, namely renewable sources. That is why we use the energy import dependency of each

country, expecting that larger energy-dependency induces higher investment in its own renewable sources. We test the following hypothesis: *H6 – Energy security objective promotes use of renewables.Income(GDP)*. The income-effect on renewables is commonly tested by literature [25,27,28]. Income could be measured, among others, by Gross Domestic Product (hereafter *GDP*) and by GDP per capita. As an explanatory variable, we use the absolute economic size measure (*GDP*), such as [25]. We will explain our option later. The hypothesis to test is: *H7 – There is a positive relationship between GDP and RE use*. Higher income could allow supporting regulatory costs to promote renewables. *Prices of oil, natural gas and coal (OILP, GASP, and COALP)*. Traditionally, the price of energy generated from conventional energy sources is lower than the price of energy generated from renewable sources. Prices of conventional sources do not internalize the environmental costs they are responsible for, not reflecting the real costs of their use [13]. Some literature also recognizes that contracts for energy produced from renewable sources can be a good way of hedging against unstable prices of fossil-based fuels [29]. Following most of the literature, for example [30,22], we control for prices of oil, natural gas, and coal. The hypothesis to test is: *H8 – Higher prices of fossil-based fuels promote the switching from traditional sources to renewable sources*. We expect to conclude that prices of traditional energy sources could be significant drivers in promoting renewables.

In this paper we cannot control for variables of public policies, such as R&D incentive programs, investment incentives, incentive taxes, incentive tariffs (mainly feed-in-tariffs), voluntary programs, compulsory renewable targets (production quotas) and tradable certificates. In fact, since our objective is to analyze the drivers from the early steps revealing environmental concerns, we are unable to include these variables due to: (i) lack of data for all countries throughout our time span; and (ii) most of these measures were adopted only after the late 1990s, such as, the compulsory renewable targets defined in EU directives.

3.2. Panel estimators

The hypothesis of persistence in the commitment to renewables requires, by its nature, a dynamic approach. Moreover, the high persistence of the share of renewables, a correlation between *CRES* in the current period and *CRES* in the previous period of about 0.97, strongly suggests the use of dynamic estimators in our panel data structure.

Since signs of autocorrelation of order one are detected, good econometric practices suggest two main alternatives: (i) removing that autocorrelation; and (ii) using techniques that can deal with it. Accordingly, to cope with the first alternative, we estimate a static fixed-effects panel model with a disturbance term being first-order autoregressive, to remove serially correlated errors. This method allows more efficient parameter estimates than the i.i.d. error model in the standard static fixed effect estimator. The model to estimate is:

$$CRES_{it} = \alpha_i + \beta X'_{it} + u_{it} \quad (1)$$

with AR(1) error $u_{it} = \rho u_{it-1} + \varepsilon_{it}$. Durbin–Watson was the method used to compute autocorrelation, where $CRES_{it}$ is the actual share of renewables in the total energy supply and X'_{it} a vector of the explanatory variables. Under the second alternative, we estimate dynamic models that specify the dependent variable depending on its values in the previous period. This option for dynamic estimators has as its main advantages: (i) eliminates countries' individual non-observable effects; (ii) handles endogeneity among explanatory variables, since their delayed values are used as instruments; (iii) handles collinearity of variables; and (iv) assesses the maintenance of commitment to renewables, allowing us to test whether the actual level of RE use is related to previous RE use. The model

to estimate is:

$$CRES_{it} = \alpha + \delta CRES_{it-1} + \beta X'_{it} + d_t + \eta_i + \varepsilon_{it} \quad (2)$$

where $CRES_{it-1}$ is the share of renewables of country i in period $t-1$, d_t are the time dummy variables, η_i are the non-observable specific effects and ε_{it} is the error term.

The difference estimator (GMM-dif) eliminates fixed effects by first-differencing [31]. The estimation of Eq. (2) is carried out with variables in first-differences and lags of *CRES* and its determinants, in levels. This procedure eliminates correlation between η_i and $CRES_{it-1}$. With highly dependent variable persistency, and when the number of periods is not large, the first-difference GMM estimator could be inefficient, since it may suffer from a severe small sample bias due to weak instruments [32]. As a solution, Blundell and Bond [32] suggest a system GMM estimator (GMM-sys). This estimator considers both first-differenced instruments for the equation in levels, and instrument in levels for the first-differenced equation. For variables in levels, instruments come in first differences while variables in first-differenced instruments come in levels. The systems of equations in levels and first differences make instruments more robust. Both GMM-dif and GMM-sys can only be considered valid after two conditions have been established: (i) restrictions created as a consequence of the use of instruments are valid; and (ii) there is no second-order autocorrelation.

Using Monte Carlo simulation, Bruno [33] stated that Least Squares Dummy Variable Corrected (LSDVC) estimator often outperforms GMM estimators, both in terms of bias and root mean squared error. The weakness of GMM estimators, which generate a large number of instruments into a context of a small number of cross-sectional units, can lead to biased and inaccurate estimated parameters. Considering our sample, we apply the LSDVC estimator. By applying those three dynamic estimators, we are able to assess whether the effect of *CRES* from the previous period on the present level of renewable use is robust.

4. Results

We detected signs of autocorrelation (Wooldridge test for autocorrelation, under H_0 : no first-order autocorrelation presents a highly significant F -statistic of 36.442), and therefore, we estimated a fixed-effects panel model (I) when the disturbance term is first-order autoregressive. Models (II) to (VI) are estimated by dynamic estimators, as stated early.

First results reveal that, individually, prices of fossil-based fuels are not statistically significant in explaining RE use, for all models (see Table B1, in Appendix B). Pursuing the principle of parsimony, we test the exclusion of prices from the models. For that purpose, both a joint significance test and a linear restriction test were performed. The null hypothesis of these coefficients jointly being zero is not rejected for all models, except for model (I) and (II). The objective of the linear restriction test is to assess whether the sum of the price coefficients estimated could be significant in explaining RE use. In all cases, we do not reject the null hypothesis (see Table 1). Therefore, in the time span considered, there is no statistical evidence to include the variables price as a driver towards renewables. The same procedure was followed to test the exclusion of *GDP*, given its non statistical significance.

Overall, equations have the desired econometric properties. As can be seen by comparing Tables B1 and B2 (in Appendix B) with Table 2, the results of the estimations, both with and without prices of fossil-based fuels and *GDP* are robust. In fact, we observe no change of signs, and similar magnitudes of the effects are achieved.

Correlation coefficients suggest the absence of collinearity among explanatory variables (see Table A2, in Appendix A). In order to dissipate doubts, we provide the Variance Inflation Factor (VIF)

test for multicollinearity. Both the mean VIF of 2.78 and the low individual VIF suggest that collinearity is not a concern here. Results of parsimonious models are shown in Table 2.

Results from estimators GMM-*dif* and GMM-*sys* are valid. As presented earlier, condition (i) is checked by providing Sargan tests. In both cases, restrictions created as a consequence of the use of instruments are valid. Condition (ii) is also checked. We cannot reject the null hypothesis of absence of second-order autocorrelation.

On the whole, the various estimators reveal great consistency and provide strong evidence that the level of renewable energy use, in the previous period, has a highly significant and positive effect, and similar magnitude. *CO2PC* emissions are correlated with lower RE use. For all estimators the effect of *CO2PC* emissions on renewables is statistically significant and negative. The effects of all traditional energy sources (coal, oil and gas) and nuclear energy source are highly significant and consistent, which is in line with a lower RE deployment. The lobbying effect is therefore corroborated. *ENERGPC* effect on renewable energy use is significant, positive, and in general, the magnitude of this effect is similar for all. Results from the LSDVC estimator show that greater energy dependency has a negative effect on RE development.

5. Discussion

Following economic theory, higher input prices tend to cause substitution for other inputs. We have tested the hypothesis that the prices of traditional fossil energy sources encourage use of renewable energy. For our time span and for the countries considered, results show that prices of fossil energy sources were not significant in explaining the use of renewables. We test the exclusion of prices both: (i) by testing nullity of individual coefficients; and (ii) by testing linear combination of coefficients. Both tests suggest the non significance of prices in explaining the use of renewables. Although this result is not the most common, it is not new in literature [21], and it deserves two comments. First, our time span does not include the escalating price of oil in 2008. Second, the theoretical support of the price effect on renewables could be more complex than the simple direct mechanism of high prices of fossil-based fuels to make renewables more attractive. In fact, costs of oil extraction are very different depending on the place of production. Once reserves have been exhausted with lower production costs, then prices would rise in line with the higher extraction costs from less accessible places, such as deep water and pre-salt. These higher prices should be incentive enough for the development of renewables, since higher fossil-based fuel prices make investment in renewables more attractive. This chain should be true in practice, but at present, the market price mechanism is not free. The extraction of cheaper oil is under the umbrella of OPEC, which is a price-maker that influences the oil supplied in the entire world. Besides not being free, the price mechanism may have other objectives, including geo-political ones. The price of oil is kept at a level that is high enough to ensure the desired returns, but not sufficient to encourage the commitment to new technologies in RE.

Like fossil-based fuel prices, GDP is not statistically significant in explaining the use of renewables for the time span and for the set of countries under review. Economic growth generates wealth, which, in turn, leads to more demand. That demand is matched with more production, which requires more energy consumption, and the more readily available energy is fossil-based. We also tested the per capita income [1], the natural logarithm or both the contemporary and lagged growth GDP rates. None of these variables was statistically significant. Following the principle of parsimony, these results suggest the exclusion of prices and GDP of the model. Tables B1 and B2 (see Appendix B) show that the presence of vari-

ables *GDP*, *OILP*, *GASP* and *COALP* does not lead to relevant changes in the estimated parameters in our parsimonious model, considering both magnitude of coefficients and statistical significance.

Energy issues, in particular energy policies, require stability over time. The use of dynamic estimators for the analysis of drivers towards the development of renewables seems to be appropriate, because they allow us to assess the maintenance of commitment to renewables. These estimators test whether current level of RE use is related to previous RE use, while they allow us to control for several sources of endogeneity, such as the bias of omitted variables. Indeed, we corroborate Hypothesis *H1* about continuous commitment to renewables, i.e., the actual level of renewable energy use depends positively on the level of renewable energy use in the previous period. Results support the need for stability in policy design, which is in accordance with those pointed out by van Rooijen and van Wees [4] for the Netherlands, and by Wang [2] for Sweden. They conclude that both the uncertainty and discontinuity of policies promoting RE are the main causes of poor development of renewables in these countries. Wüstenhagen and Bilharz [5] corroborate the former view, concluding that a consistent policy support is a valid contribution to the use of renewables.

Concerns about climate change are at the core of the various international treaties and commitments. To deal with this issue, nations are setting targets to reduce their carbon emissions, both on a voluntary and compulsory basis. Results suggest that *CO2PC* emissions discourage RE use, consistently throughout all the estimators. This result suggests that the current levels of *CO2PC* are not enough to switch to renewables. On the contrary, these levels remain as incentives for continuing to burn fossil-based fuels. Social pressure seems not to have been sufficient to stimulate renewables. Accordingly, it is necessary to create social awareness among the population about the sustainability of the planet, particularly among children, an example of which can be seen in the energy parks set up in educational institutions in India [12]. Moreover, international agreements must be more ambitious in reducing the allowed levels of emissions.

Our results provide evidence on the effect of lobbying exercised by traditional energy sources in restraining the deployment of renewables. We accept Hypothesis *H4*. The greater the contribution of fossil sources in the generation of energy, the smaller the deployment of renewables. As seen in [24], we found that the lobby effect delays RE commitment. The fossil-based fuel industries have been funding political campaigns around the world. Politicians and policymakers are primarily concerned with the current levels of wealth and quality of life. That option leads to the maintenance or even increase in energy consumption at the lowest cost, since it is expected that the consequences of climate change and global warming will be felt only in the medium/long run. By that time, re-election is no longer a goal. Moreover, fossil-based fuels have also been used as a powerful geo-strategic weapon, with direct impact on the military industry, employment, capital markets and the economy in general.

We accept Hypothesis *H5*. Nuclear source technology requires the large-scale use, then replacing other sources, such as renewables. In Sweden [2], the nuclear issue causes political bewilderment concerning the energy policy, making it difficult to commit to renewables. It is worth noting that among traditional energy sources, natural gas and nuclear power are not heavy polluters. Natural gas can also be a transition energy source, given that it is a fuel that releases less carbon and is more powerful than oil.

We show that *ENERGPC* is a meaningful variable to explain the use of renewables. Energy consumption encourages their use. Results suggest that additional energy needs could also stimulate production from RE sources and not just from traditional ones. The self-sufficiency energy objective is statistically highly significant in the Bias-Corrected LSDV estimator, but we do not accept Hypoth-

Table A1

Data: definition, sources and descriptive statistics.

Variable	Definition	Source	Obs	Mean	SD	Min	Max
$CRES_{i,t}$	Contribution of renewables to energy supply (% of total primary energy supply)	OECD Factbook 2009	408	11.1503	14.2007	0.2	75.3
$CO2PC_{i,t}$	CO ₂ per capita (kg/cap)	Eurostat, December 2008, EC, DG TREN	408	10244.1	4699.821	2488.11	33363.39
$ENERGPC_{i,t}$	Per capita energy (kgOe/cap)	Eurostat December 2008, EC, DG TREN	408	4168.576	2081.574	930	14290.2
$SOILEG_{i,t}$	Importance of oil to electricity generation (%)	Ratio electricity generation oil/total elect. Generation. Eurostat December 2008, EC, DG TREN	408	6.6373	9.5843	0	51
$SGASEG_{i,t}$	Importance of gas to electricity generation (%)	Ratio electricity generation gas/total elect. Generation. Eurostat December 2008, EC, DG TREN	408	15.6740	17.0109	0	76
$SCOALEG_{i,t}$	Importance of coal to electricity generation (%)	Ratio between electricity generation coal (TWh) and total elect. generation (TWh). Eurostat December 2008, EC, DG TREN	408	33.1054	27.7188	0	97
$SNUCLEG_{i,t}$	Importance of nuclear to electricity generation (%)	Ratio electricity generation nuclear/total elect. generation. Eurostat December 2008, EC, DG TREN	408	20.3186	22.7419	0	78
$IMPTDP_{i,t}$	Import dependency of energy (%)	Eurostat December 2008, EC, DG TREN	408	51.9141	28.2772	-50.83	99.8
$GDP_{i,t}$	Real gross domestic product (billions of dollars, 2005)	World Bank World Development Indicators, and International Financial Statistics of the IMF	408	510.3501	707.5579	6.75	2883.12
$OILP_{i,t}$	Oil price (US dollars per barrel, 2008)	BP Statistical Review of World Energy 2009	408	33.6884	13.0498	17.3219	69.5805
$GASP_{i,t}$	Natural gas price (US dollars per million Btu, 1995)	BP Statistical Review of World Energy 2009	408	3.4116	1.3672	1.7868	7.5777
$COALP_{i,t}$	Coal price (US dollars per ton, 1995)	BP Statistical Review of World Energy 2009	408	42.3673	10.3638	28.5785	67.2906

Table A2
Correlation matrix.

	$CRES_{i,t}$	$CO2PC_{i,t}$	$ENERGPC_{i,t}$	$SOILEG_{i,t}$	$SGASEG_{i,t}$	$SCOALEG_{i,t}$	$SNUCLEG_{i,t}$	$IMPTDP_{i,t}$	$GDP_{i,t}$	$OILPC_{i,t}$	$GASP_{i,t}$	$COALP_{i,t}$
$CRES_{i,t}$	1											
$CO2PC_{i,t}$	−0.174***	1										
$ENERGPC_{i,t}$	0.529***	0.652***	1									
$SOILEG_{i,t}$	−0.167***	−0.219***	−0.384***	1								
$SGASEG_{i,t}$	−0.318***	0.373***	0.079	0.114**	1							
$SCOALEG_{i,t}$	−0.377***	0.031	−0.406***	0.013	−0.211***	1						
$SNUCLEG_{i,t}$	−0.139***	−0.228***	0.017	−0.342***	−0.314***	−0.362***	1					
$IMPTDP_{i,t}$	−0.112**	0.106**	−0.004	0.348***	0.164***	−0.415***	0.036	1				
$GDP_{i,t}$	−0.248***	−0.120**	−0.115**	0.099**	0.084*	−0.079	0.261***	−0.068	1			
$OILPC_{i,t}$	0.030	0.032	0.073	−0.135***	0.187***	−0.055	−0.001	0.026	0.050	1		
$GASP_{i,t}$	0.031	0.034	0.077	−0.135***	0.191***	−0.055	−0.001	0.026	0.052	0.939***	1	
$COALP_{i,t}$	0.007	0.046	0.041	−0.078	0.076	−0.008	0.003	0.019	0.016	0.690***	0.639***	1

Notes: ***, **, * significant at 1%, 5% and 10% significance, respectively.

esis H6 as valid. For our time span and for the countries analyzed, results do not confirm the stimulus effect suggested by some literature [23] on the energy dependency of RE use. This result may be an indicator of the vicious circle into which a country enters when it uses heavily fossil sources. The higher energy imports are, the lower the commitment is to renewables and hence there is less commitment to their development. Renewables may, in fact, lead to increased fossil-based fuel imports (namely natural gas), given the specific nature of the cyclical behavior of their production, and the need for uninterrupted supplies. It is therefore necessary to develop a mix of renewables that will ensure continuous production and avoid creating excess idle capacity, such as combined cycle power plants, which increase the energy costs of a country. The viability of these policies may imply the need for transnational policies.

6. Conclusion

We analyze drivers towards the use of renewables for a set of twenty-four European countries, from the year 1990 to 2006. The use of dynamic estimators proved to be appropriate. They allow us: (i) to analyze the commitment to renewables as a dynamic process; (ii) to deal with the persistent weight of renewables in total

energy supply; (iii) to eliminate countries' non-observable individual effects; and (iv) to control for both endogeneity, by using instrumental variables, and collinearity among explanatory variables. The dynamic estimators reveal great consistency of results.

Our study provides strong evidence of the persistency effect. In fact, the level of renewable energy use in the previous period has a positive and highly significant effect on the current one. Traditional energy sources curb the impetus towards renewables. We do not find evidence that social awareness about climate change mitigation and CO₂ reduction is enough, in the period under analysis, to motivate the switch from traditional to renewable energy sources.

Income and prices of fossil-based fuels were not decisive for the development of renewables over the analyzed period. Therefore, it was not the market that encouraged renewables, but other factors instead. If the price mechanism works freely, high prices could anticipate the scarcity of these fuels in the long run, which would lead to an increase in renewables. This does not happen at present, probably because the market is cartelized. Moreover, the prices of traditional sources may now be constrained by the falling prices of renewable resources, which is a result of progress in technology. It is like a feedback hypothesis. This is an issue that deserves attention for further research.

Table B1
Results from models with all variables.

Independent variable	Dependent variable $CRES_{i,t}$					
	(VI) Fixed effects (AR1)	(VII) GMM-dif	(IX) GMM-sys	LSDVC		
				(X) Initial (AB)	(XI) Initial (AH)	(XII) Initial (BB)
$CRES_{i,t-1}$		0.3429*** (0.1000)	0.7066*** (0.0851)	0.6214*** (0.0439)	0.6210*** (0.0530)	0.7113*** (0.0371)
$CO2PC_{i,t}$	−0.0002** (0.0001)	−0.0004*** (0.0001)	−0.0003* (0.0001)	−0.0002*** (0.0001)	−0.0002*** (0.0001)	−0.0002** (0.0001)
$ENERGPC_{i,t}$	0.0010*** (0.0002)	0.0012*** (0.0004)	0.0009* (0.0004)	0.0008*** (0.0002)	0.0008*** (0.0002)	0.0006*** (0.0002)
$SOILEG_{i,t}$	−0.1581*** (0.0177)	−0.1780*** (0.0561)	−0.1364*** (0.0505)	−0.0817*** (0.0176)	−0.0795*** (0.0206)	−0.0883*** (0.0185)
$SGASEG_{i,t}$	−0.0750*** (0.0116)	−0.0965* (0.0552)	−0.0857 (0.0523)	−0.0520*** (0.0116)	−0.0526*** (0.0138)	−0.0523*** (0.0120)
$SCOALEG_{i,t}$	−0.1329*** (0.0166)	−0.1210*** (0.0401)	−0.1219*** (0.0310)	−0.0618*** (0.0146)	−0.0593*** (0.0180)	−0.0645*** (0.0156)
$SNUCLEG_{i,t}$	−0.2663*** (0.0233)	−0.2430** (0.1102)	−0.1723*** (0.0859)	−0.1357*** (0.0237)	−0.1318*** (0.0275)	−0.1407*** (0.0243)
$IMPTDP_{i,t}$	−0.0466*** (0.0108)	−0.0254 (0.0155)	−0.0128 (0.0168)	−0.0217*** (0.0076)	−0.0235** (0.0095)	−0.0202*** (0.0075)
$GDP_{i,t}$	−0.0039** (0.0017)	−0.0028 (0.0036)	−0.0016 (0.0021)	−0.0012 (0.0009)	−0.0011 (0.0011)	−0.0012 (0.0009)
$OILPC_{i,t}$	0.0115 (0.0070)	0.0134 (0.0087)	0.0029 (0.0099)	0.0157 (0.0109)	0.0157 (0.0121)	0.0118 (0.0119)
$GASP_{i,t}$	0.0853 (0.0624)	−0.0675 (0.1148)	−0.0321 (0.1111)	−0.0360 (0.1018)	−0.0368 (0.1114)	−0.0434 (0.1117)
$COALP_{i,t}$	−0.0035 (0.0049)	−0.0037 (0.0054)	−0.0012 (0.0047)	−0.0013 (0.0070)	−0.0013 (0.0077)	0.0001 (0.0078)
CONS	25.373*** (0.3632)	20.219*** (6.4274)	14.212*** (3.7084)			
Instruments		GMM-dif	GMM-sys			
Observations	384	360	384	384	384	384
Wald(χ^2)		171.92	1528.76			
$F(N(0,1))$	31.35***					
Sargan(χ^2)		12.339	11.482			
$m1(N(0,1))$		−2.487**	−2.468**			
$m2(N(0,1))$		1.071	1.095			

Notes: ***, **, * significant at 1%, 5% and 10% significance, respectively.

Table B2

Results from models without prices of fossil-based fuels.

Independent variable	Dependent variable $CRES_{i,t}$					
	(XIII) Fixed effects (AR1)	(XIV) GMM-dif	(XV) GMM-sys	LSDVC		
				(XI) Initial (AB)	(XII) Initial (AH)	(XIII) Initial (BB)
$CRES_{i,t-1}$		0.3348*** (0.1054)	0.6693*** (0.0828)	0.6396*** (0.0415)	0.6381*** (0.0490)	0.7225*** (0.0354)
$CO2PC_{i,t}$	–0.0002** (0.0001)	–0.0004*** (0.0001)	–0.0003** (0.0001)	–0.0002*** (0.0001)	–0.0002*** (0.0001)	–0.0002** (0.0001)
$ENERGPC_{i,t}$	0.0011** (0.0002)	0.0012*** (0.0004)	0.0009** (0.0004)	0.0008*** (0.0002)	0.0008*** (0.0002)	0.0006*** (0.0002)
$SOILEG_{i,t}$	–0.1692*** (0.0176)	–0.1809*** (0.0382)	–0.1462*** (0.0342)	–0.0882*** (0.0176)	–0.0851*** (0.0204)	–0.0917*** (0.0183)
$SGASEG_{i,t}$	–0.0722*** (0.0117)	–0.0861* (0.0467)	–0.0821** (0.0342)	–0.0493*** (0.0114)	–0.0498*** (0.0132)	–0.0510*** (0.0118)
$SCOALEG_{i,t}$	–0.1367*** (0.0167)	–0.1269*** (0.0351)	–0.1320*** (0.0465)	–0.0661*** (0.0149)	–0.0631*** (0.0170)	–0.0659*** (0.0157)
$SNUCLEG_{i,t}$	–0.2642*** (0.0235)	–0.2816*** (0.1047)	–0.2020*** (0.0538)	–0.1302*** (0.0235)	–0.1253*** (0.0267)	–0.1374*** (0.0239)
$IMPTDP_{i,t}$	–0.0426*** (0.0110)	–0.0133 (0.0124)	–0.0079 (0.0158)	–0.0188** (0.0074)	–0.0199** (0.0092)	–0.0186** (0.0073)
$GDP_{i,t}$	–0.0017 (0.0016)	–0.0032 (0.0027)	–0.0023 (0.0017)	–0.0009 (0.0008)	–0.0008 (0.0009)	–0.0010 (0.0008)
CONS	24.373*** (0.3417)	20.171*** (4.9695)	15.725*** (3.0280)			
Instruments		GMM-dif	GMM-sys			
Observations	384	360	384	384	384	384
Wald(χ^2)		6320.31	1687.44			
$F(N(0,1))$	40.54***					
Sargan(χ^2)		13.395	13.085			
$m1(N(0,1))$		–2.249**	–2.4679**			
$m2(N(0,1))$		0.967	1.0199			

Notes: ***, **, * significant at 1%, 5% and 10% significance, respectively.

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Appendix A.

See Tables A1 and A2.

Appendix B.

See Tables B1 and B2.

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